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SUPERNOVA SEARCH OPTIMIZATION: APPLICATION TO THE DARK ENERGY SURVEY

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Postdoctoral Research Symposium

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Argonne National Laboratory

Outline

- Introduction to cosmology
- Dark energy: evidence & alternatives
- The Dark Energy Survey
- Summary & conclusions

DARK ENERGY SURVEY

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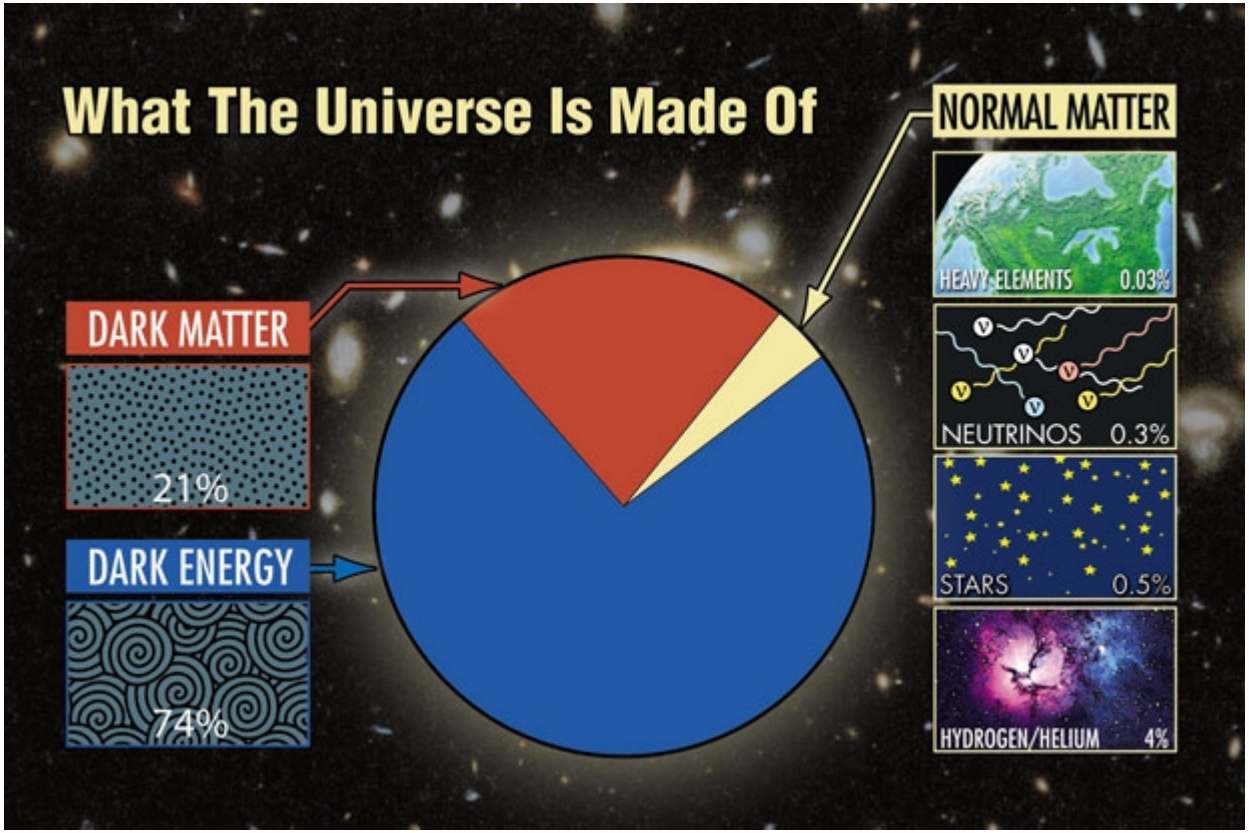
Fundamental Motivation

DARK ENERGY SURVEY

Discovering the evolution & ultimate fate of the Universe and determining what constitutes 95% of the Universe!

Have A Slice Of Universe Pie



Courtesy: http://hetdex.org

Dark Energy Requires Fundamental Particle Physics Change

DARK ENERGY SURVEY

- Motivated U.S. Dept. of Energy to invest in astrophysics
  - proposed major new astrophysics funding
  - comparison: ~$10M/year previously
- Is it Einstein's vacuum energy?
  - aka, the Cosmological Constant (Λ)
  - best estimate of current theory is off by factor of at least 10^{60}
- New fundamental, zero-spin, scalar particle? Predicted in particle physics & inflation models, but nothing like it ever observed directly
- Modified Theory of Gravity: hypothesis that Einsteinian gravity breaks down at large scales?

Quantifying Past & Future Evolution

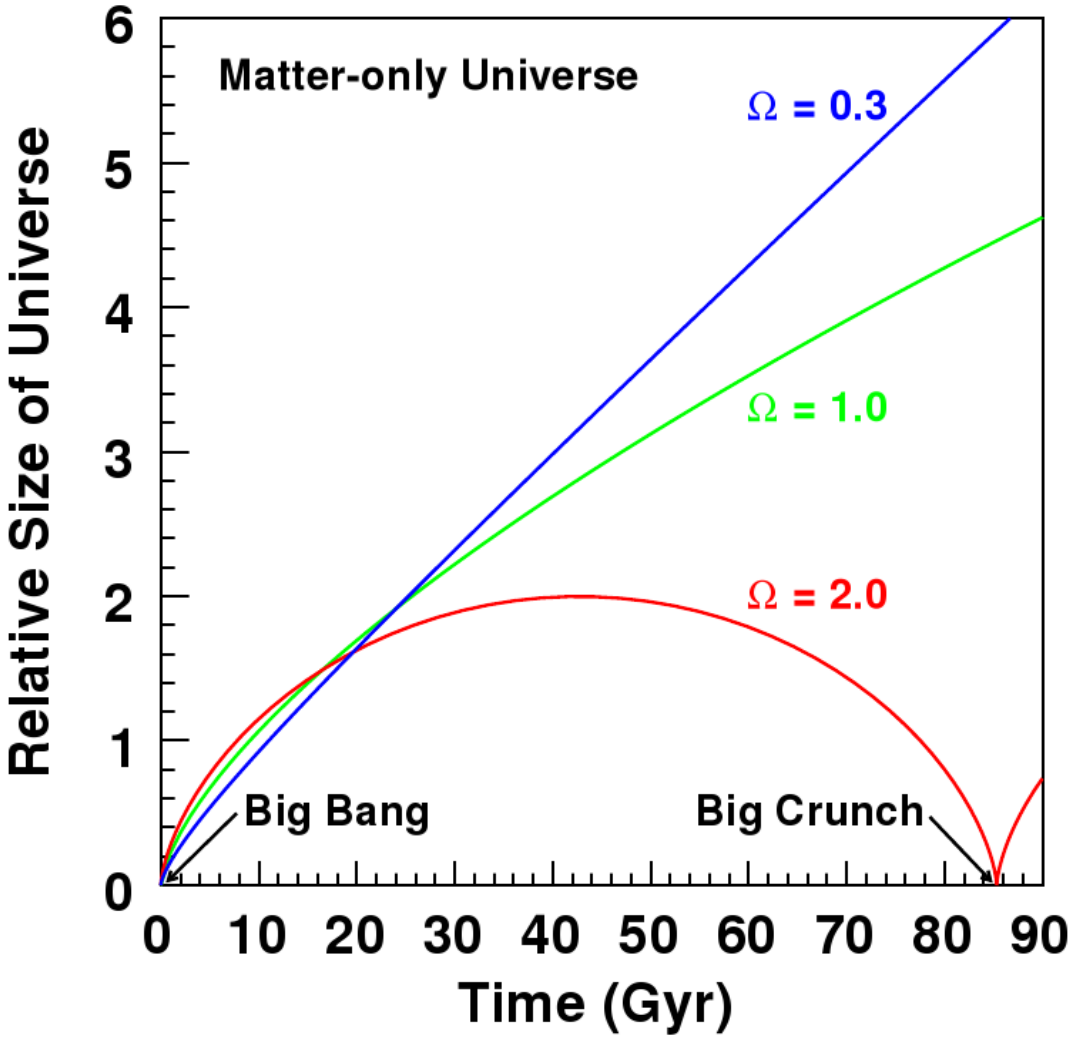
DARK ENERGY SURVEY

Observation:
Universe is expanding

Evolution depends on energy density ρ

Define: $\Omega \equiv \rho/\rho_{crit}$

ρ_{crit}: matter density required to make the Universe geometrically flat (i.e., shortest distance between two points is a straight line).



Quantifying Cosmology

DARK ENERGY SURVEY

Theory motivates & data show that Universe has:

$$\Omega_{\text{tot}} = 1$$

Observations indicate matter comprises only 25%:

$$\Omega_{\text{m}} = 0.25$$

What makes up the other 75%?

Towards An Answer: Type Ia Supernovae

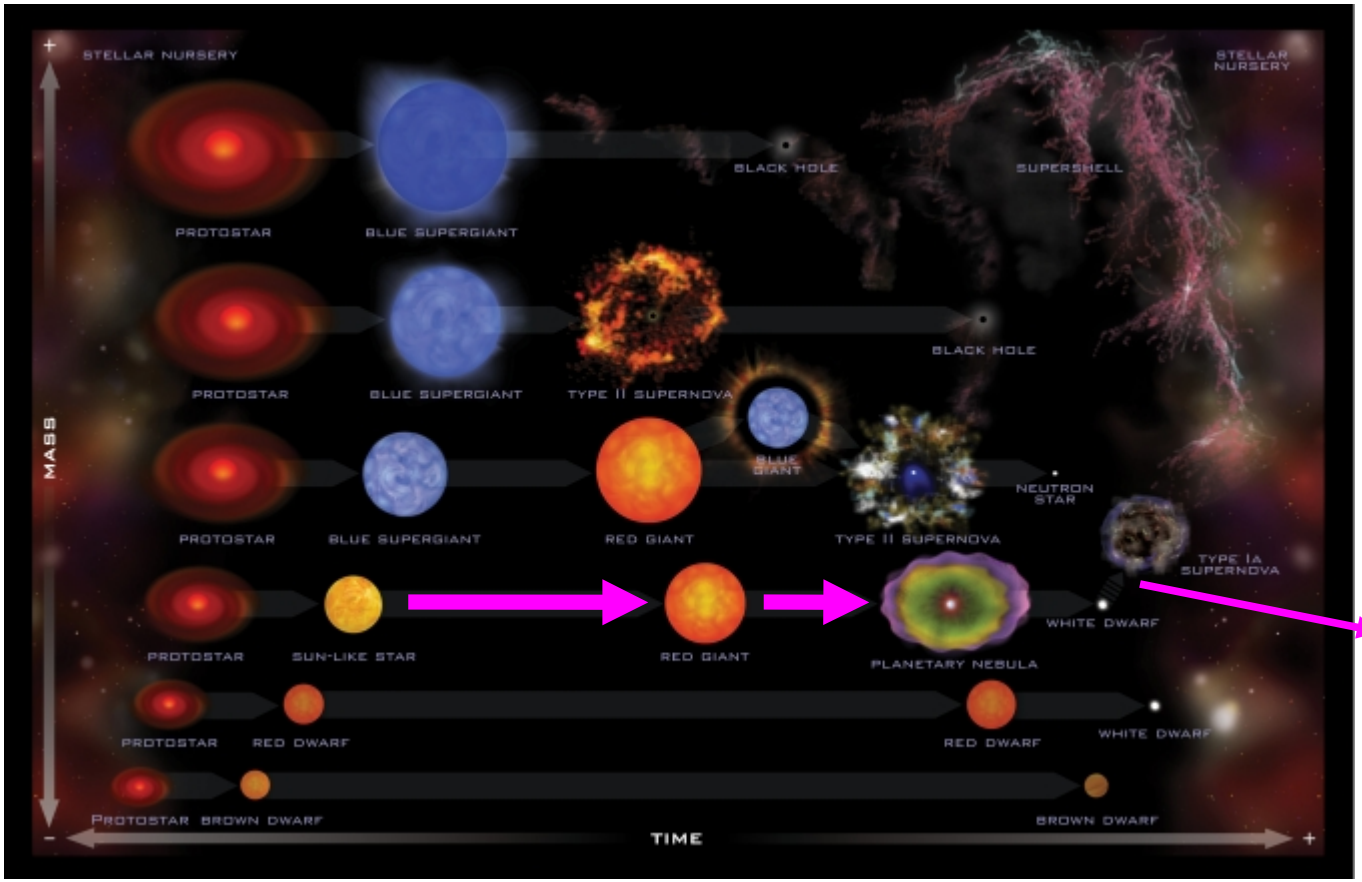
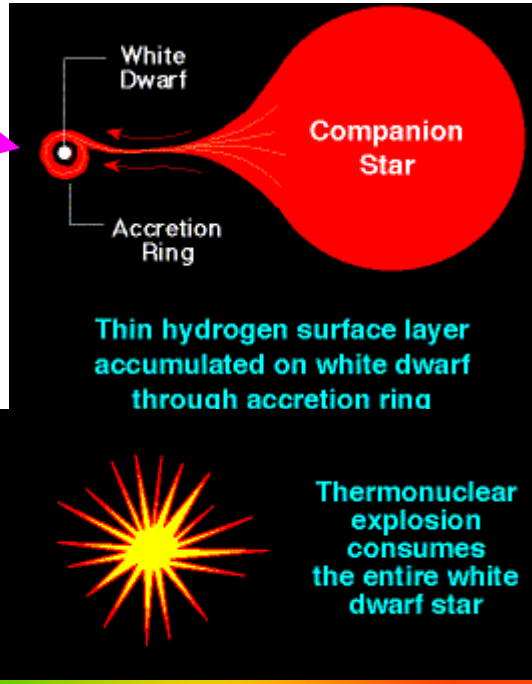
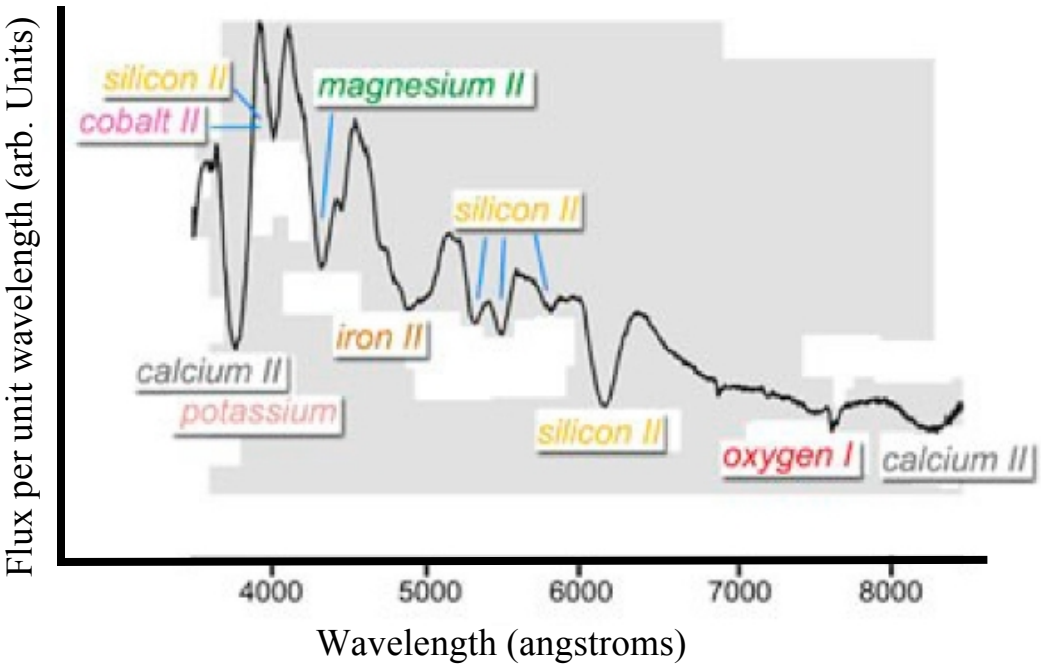


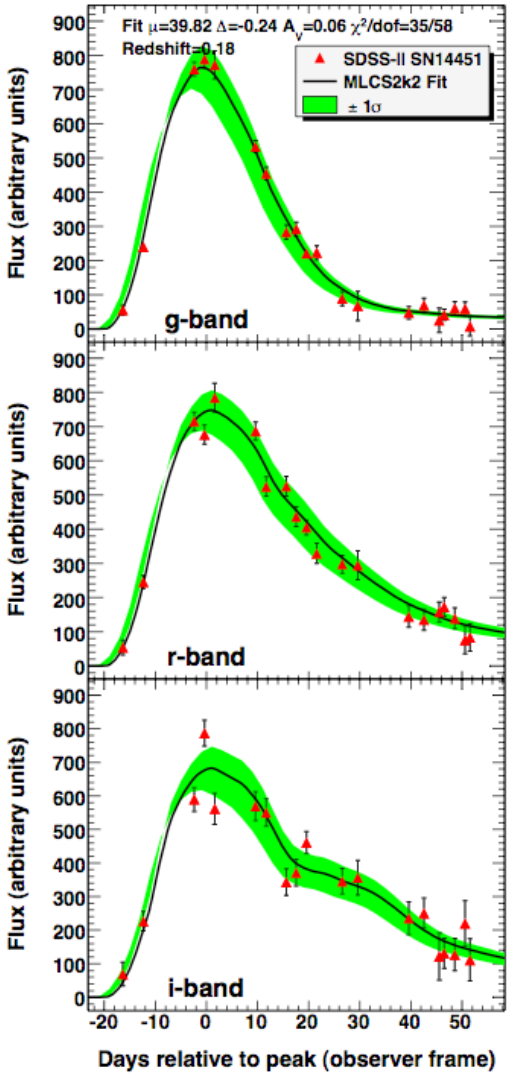
Image courtesy http://www.siprep.org/faculty/aokeefe

Figure courtesy
http://csep10.phys.utk.edu/astr162



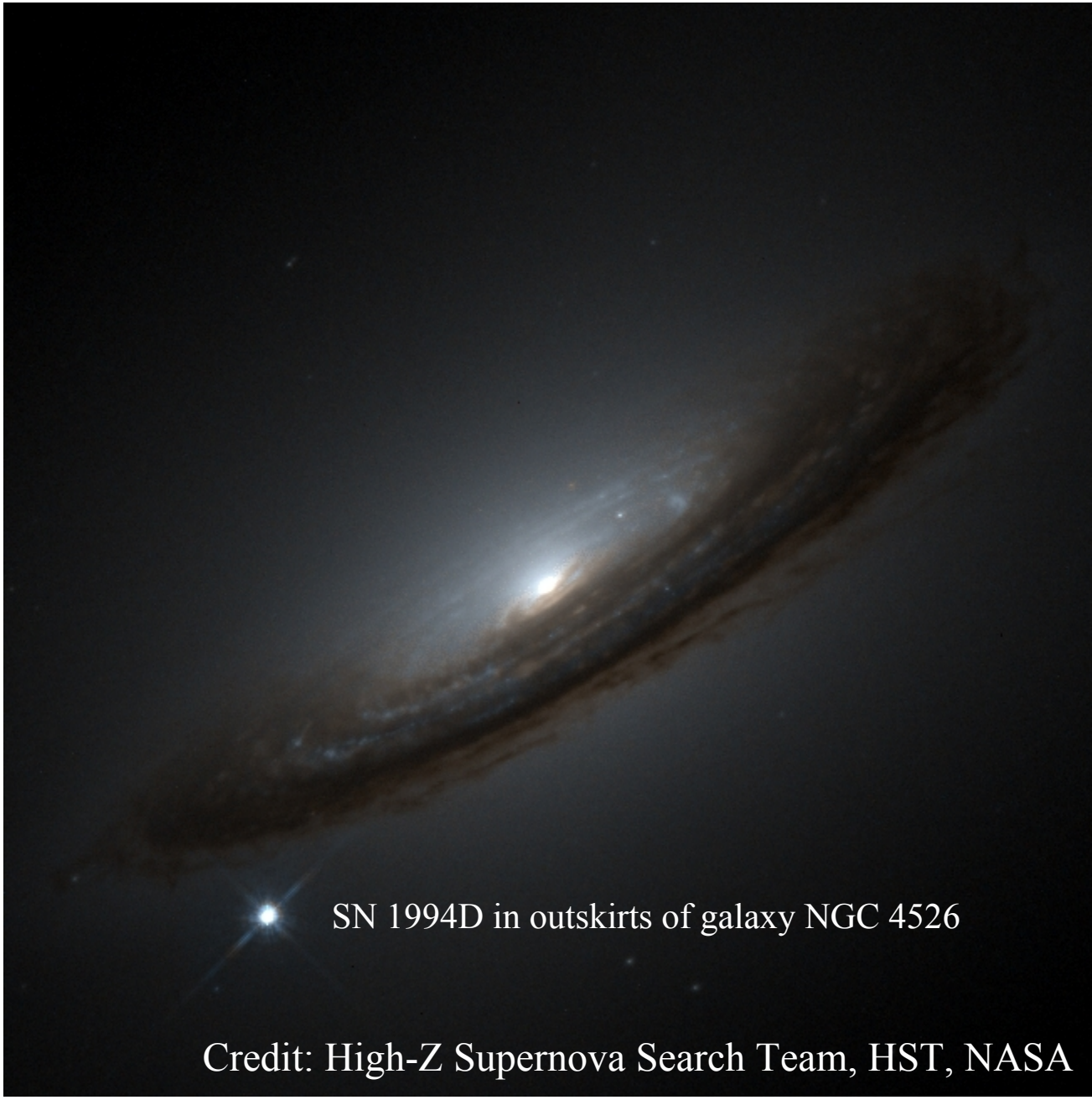
Example Type Ia Supernova Spectrum & Light Curve





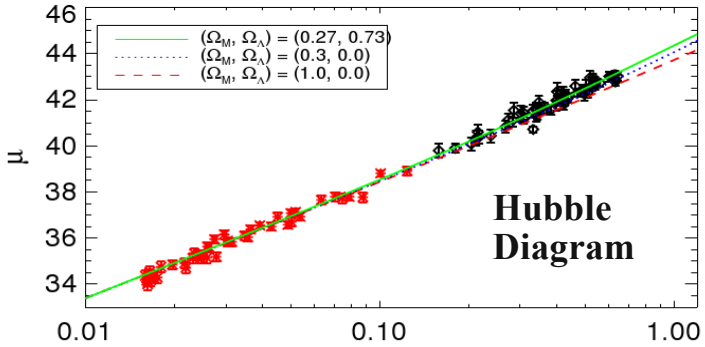
BRIGHT!

NCG 4526 is ~55 million light years away from Earth ⇒ the light from SN 1994D started traveling towards Earth ~55 million years before 1994!

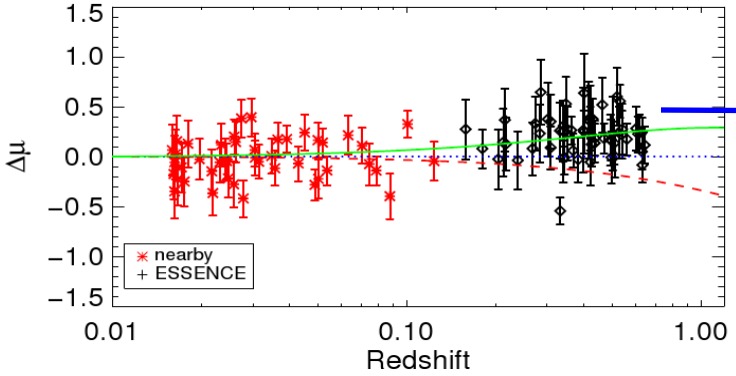


Type Ia SNe As Standard Candles

DARK ENERGY SURVEY



Credit: W. M. Wood-Vasey et al. 2008, ApJ, 666, 694



dimmer

$1 + z \equiv \lambda_{obs}/\lambda_{emit}$

$z \equiv$ *redshift*

λ_{obs} = observed wavelength

λ_{emit} = emitted wavelength

NB. distance $\propto$ func(z,Ω)

Distance modulus:

$\mu = 5\log_{10}(d/10\ pc)$

d = distance (1 pc = 3.09x10^{16} m)

mu	distance
25	1 Mpc (Andromeda)
30	10 Mpc
35	100 Mpc
40	1 Gpc
45	10 Gpc (close to Big Bang)

Distant SNe dimmer than predicted for a matter-only Universe!

Discovery:

S. Perlmutter et al., Nature, 391, 51 (1998);

Reiss et al., Astronomical J., 116, 1009 (1998)

Quantitative Framework For Dark Energy

DARK ENERGY SURVEY

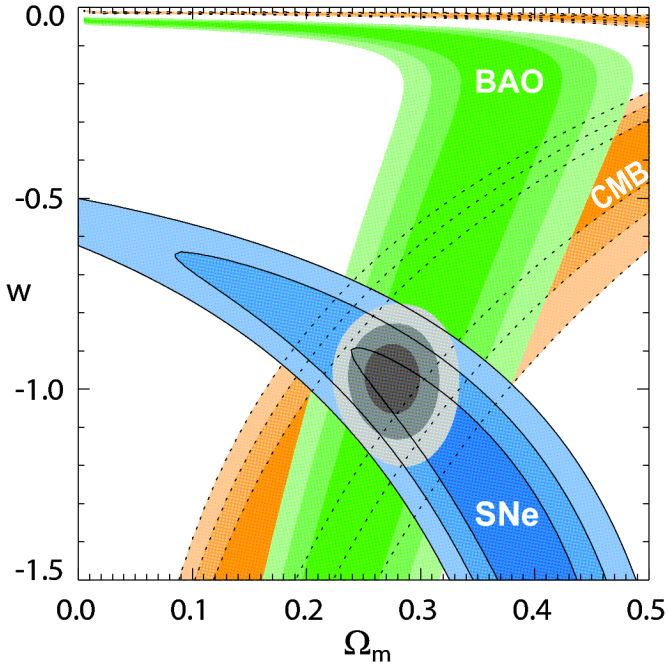
Explanation: expansion of Universe is accelerating due to dark energy that has strongly negative pressure (p_{DE})

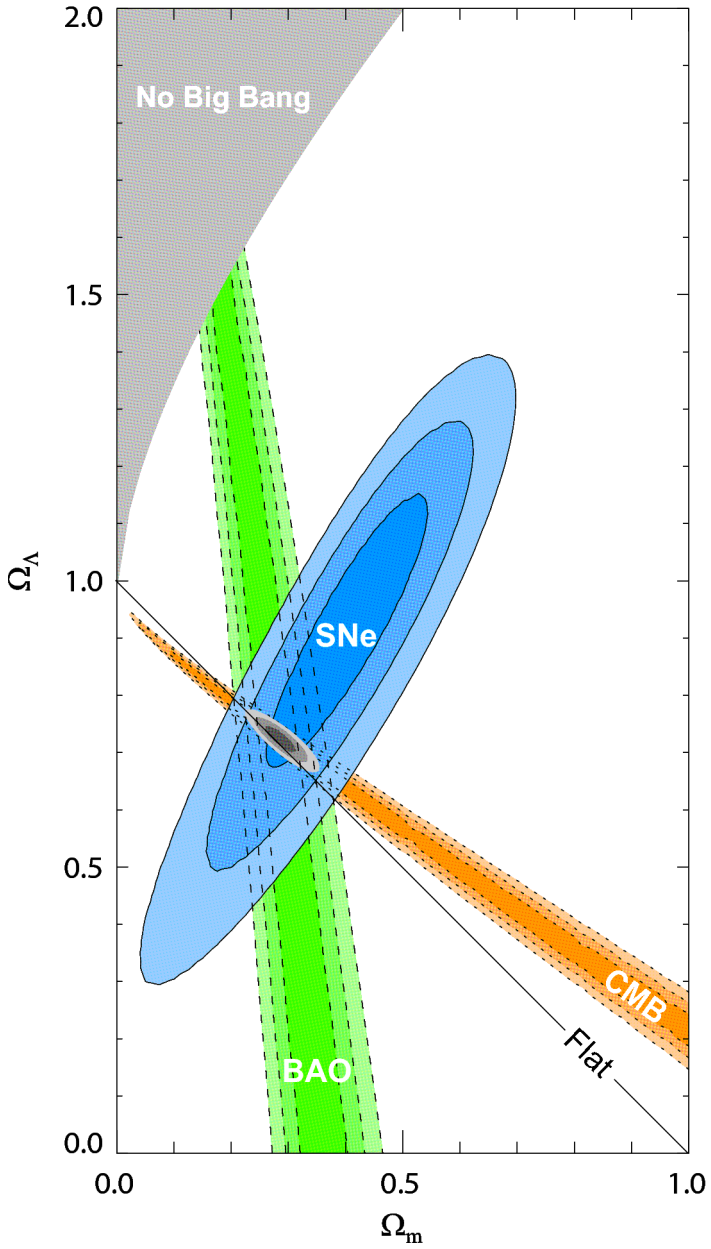
Dark energy equation of state: $w = p_{DE}/\rho_{DE}$

Dark energy density today: $\Omega_{DE} = \rho_{DE}/\rho_{crit}$

Default cosmology: w = -1
Einstein's cosmological constant (Λ)

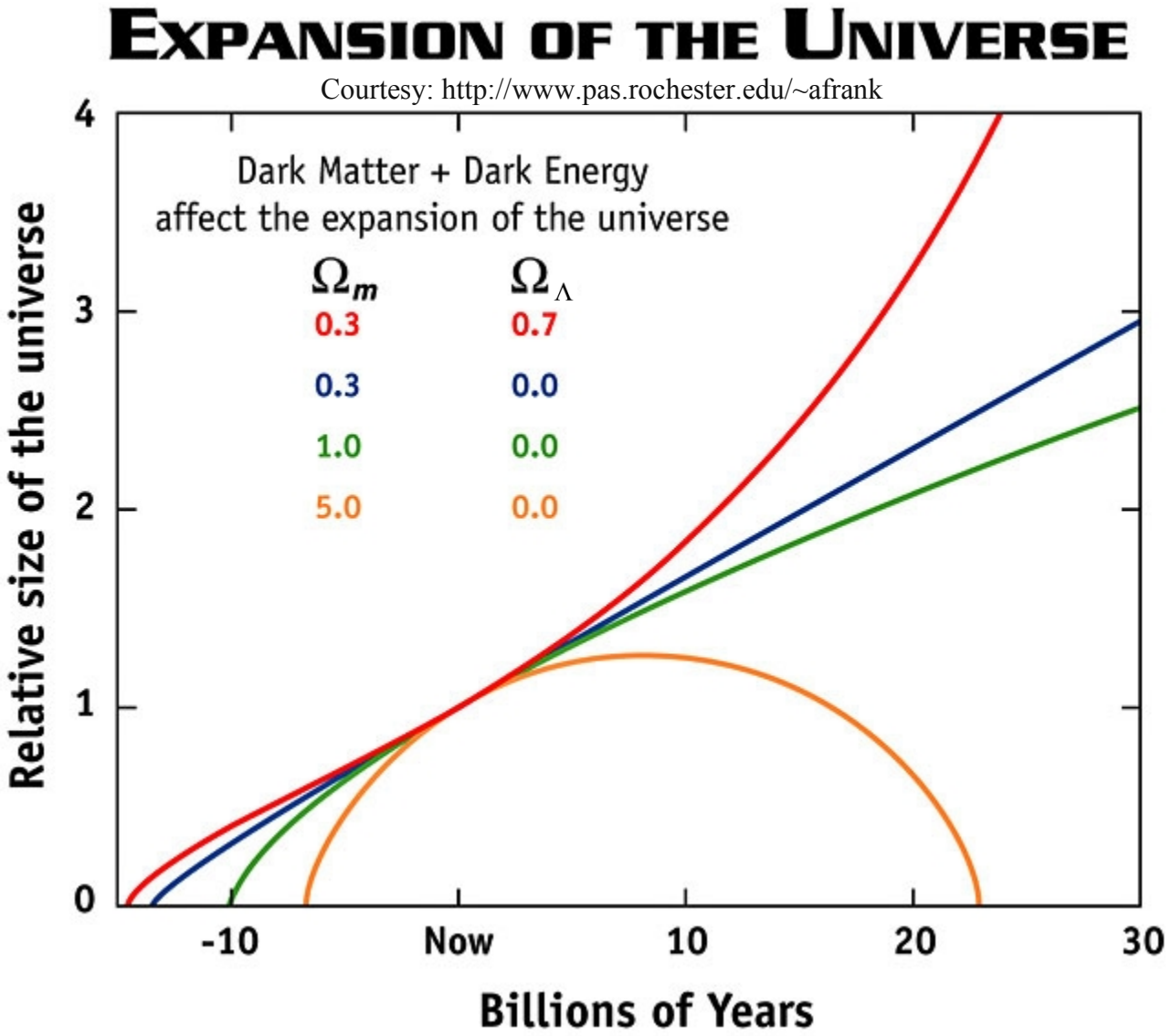
Current Constraints





Credit: Kowalski et al. 2008, ApJ, 686, 749

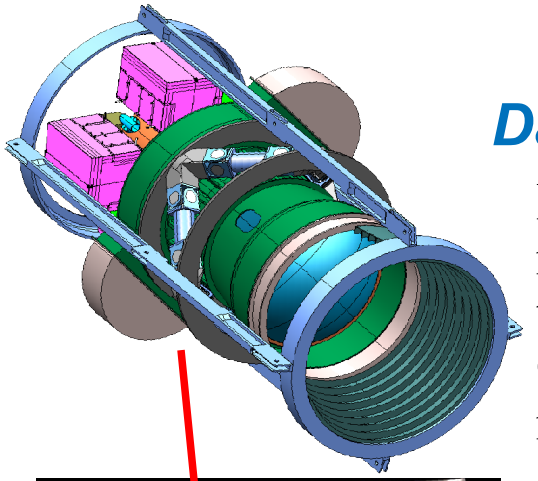
Expansion Revisited



Alternatives to Dark Energy (DE)?

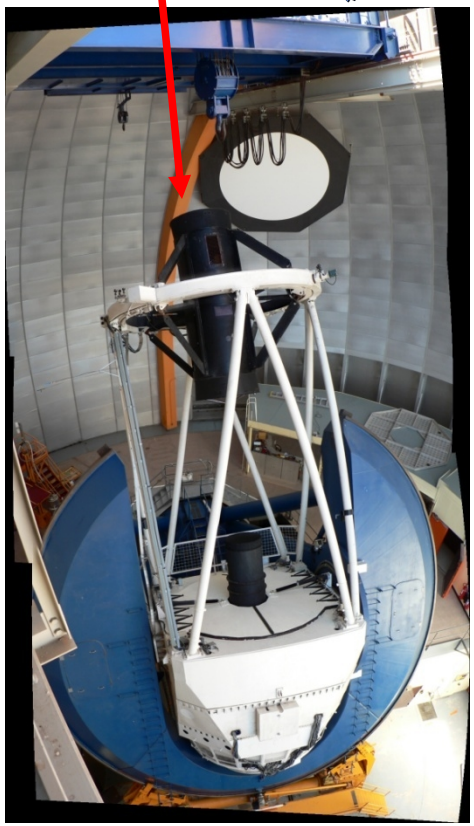
DARK ENERGY SURVEY

- Modified Gravity (MG)?
  - recall: hypothesis gravity breaks down at large scales
  - conflicts with strong evidence for dark *matter* (DM)
  - however, could have dark matter + MG instead of DE, e.g.
    - DM to explain galactic rotation curves and cluster dynamics
    - MG to explain dimness of SN Ia
  - in either case, must result in observed expansion
  - currently very difficult to distinguish effects of DE and MG
- Hubble Bubble
  - hypothesis that local expansion rate deviates from average
  - suggestive evidence exists
  - more study required
- Any alternative must explain different & independent DE evidence



Dark Energy Survey (DES)

DES will survey 5000 square degree of sky and provide new 500Mpixel CCD camera (DECAM) for Blanco 4m telescope at the Cerro Tololo Inter-American Observatory (CTIO), Chile, in exchange for 525 survey nights over 5 years starting in 2011.



ANL DES group: Joe Bernstein, Jim Grudzinski, Vic Guarino, Steve Kuhlmann, Hal Spinka, Rich Talaga, Allen Zhao.

DE investigation via 4 independent probes:
1) Galaxy angular clustering
2) Weak gravitational lensing
3) Baryon acoustic oscillations
4) SN Ia distances

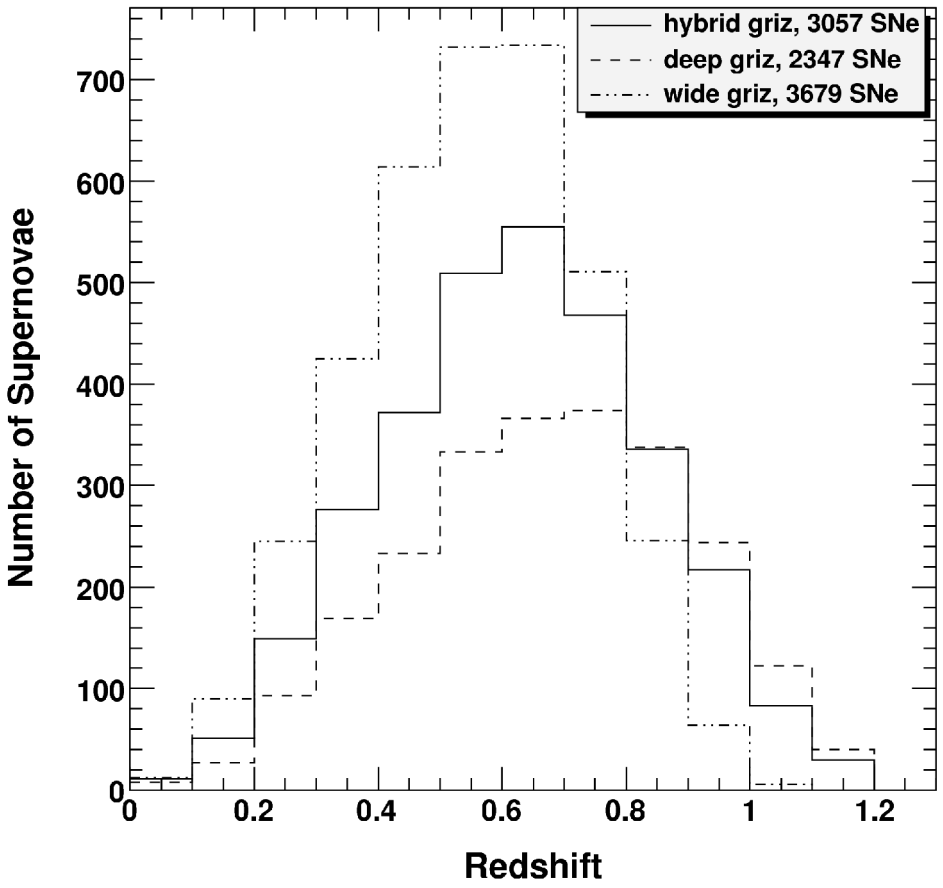
DES is expected to observe ~10^8 galaxies & will obtain redshifts for the South Pole Telescope survey.

SNANA: SuperNova ANAlysis package for DES

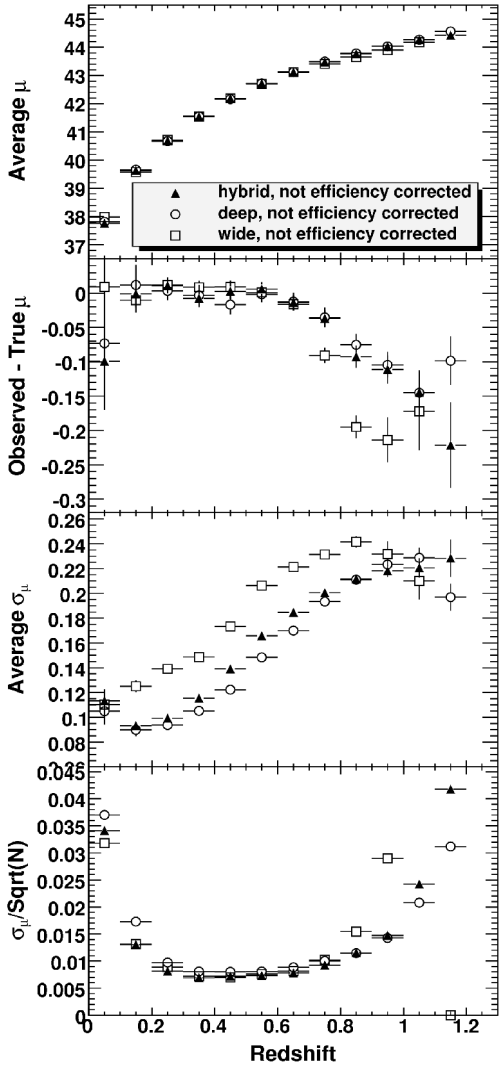
R. Kessler (U. Chicago), J. P. Bernstein, S. Kuhlmann, & H. Spinka (ANL)

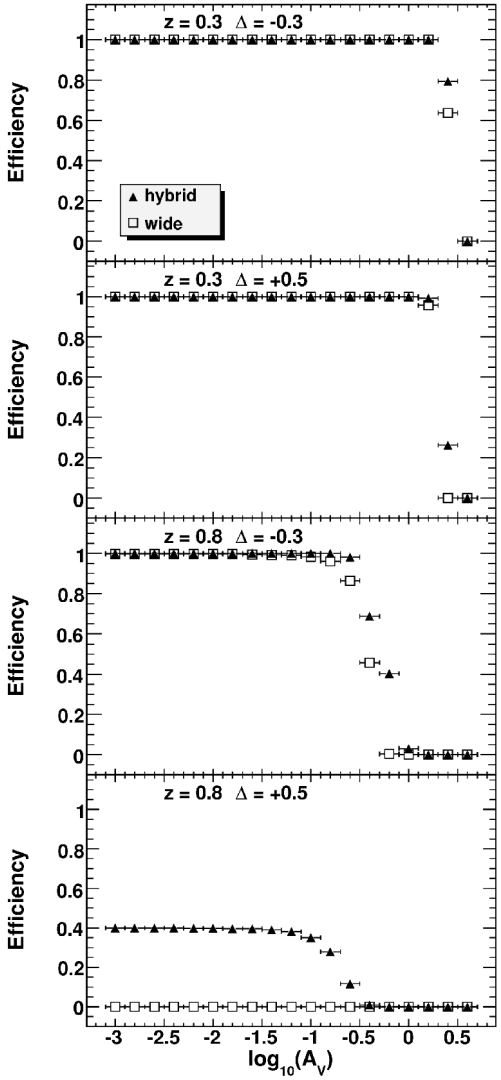
- Public URL: http://www.sdss.org/supernova/SNANA.html
- Also used by Sloan Digital Sky Survey & Large Synoptic Survey Telescope
- Software for simulating (both Ia & non-Ia) and fitting SN light curves
- Uses various models (e.g., MLCS2k2, SALT-II, stretch, etc.)
- Simulation steps
  - Generate rest-frame luminosity and fluctuations
  - Apply host galaxy dust extinction
  - Make redshift correction
  - Apply Milky Way dust map based on trajectory
  - Apply CTIO weather history effects, sky noise including angular separation of the Moon, and detector effects

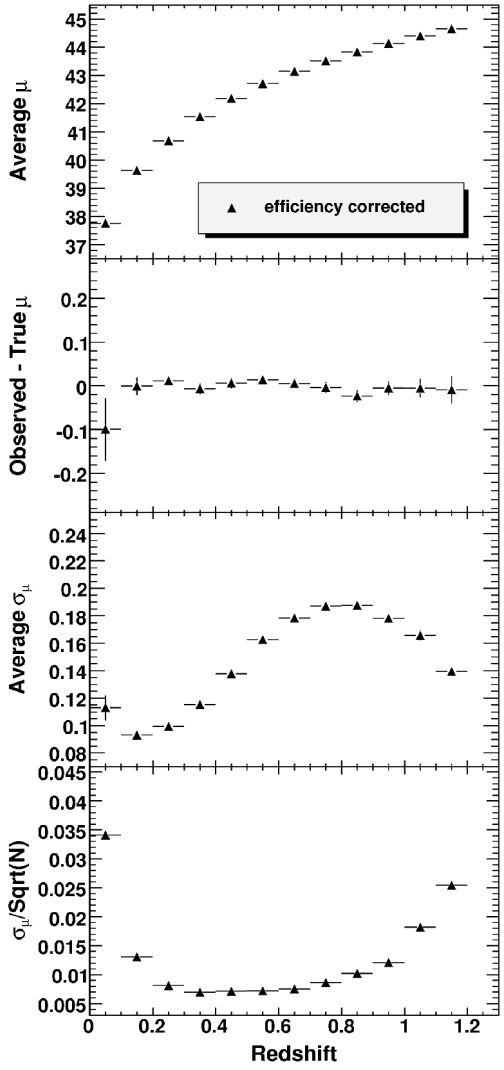
DES Number of Type Ia Supernovae SNANA Forecast



Type Ia SN Selection Bias & SNANA Forecasted Hubble Diagram







Core Collapse Supernova Characteristics

- Type Ibc
  - have light curves most similar to Type Ia light curves
  - Type Ib spectra show helium lines, Type Ic spectra do not
- Type IIP: Hydrogen lines + plateau in late time light curve
- Type IIL: Hydrogen lines + linear decline in late time light curve
- Type IIn: Hydrogen lines + exhibit narrow emission lines

DES Contamination of the Type Ia Sample SNANA Forecast

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Assume 100% host galaxy spectra (Spectrometric Redshifts)		
Type	# of SNe pass default cuts	# of SNe pass default cuts + fit. prob. > 0.1
Ia	3066	2954
Ibc	486	183
IIP	775	10
IIL	112	10
IIn	1417	26

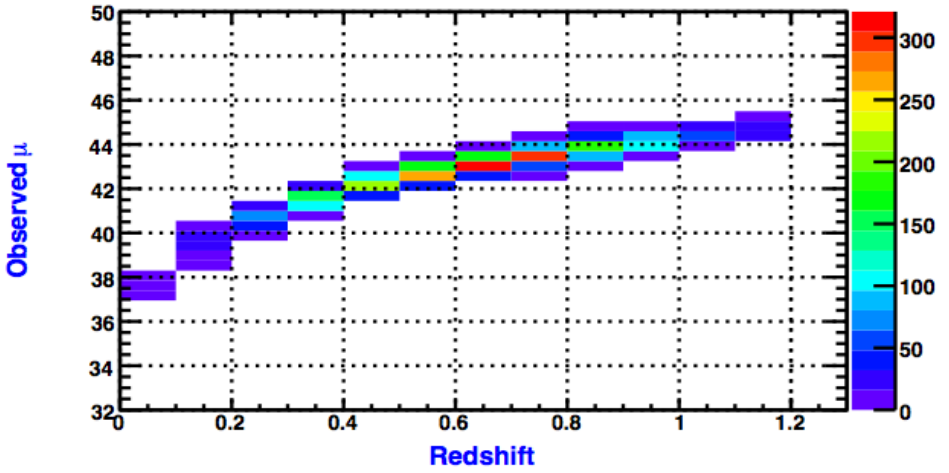
Default cuts

At least

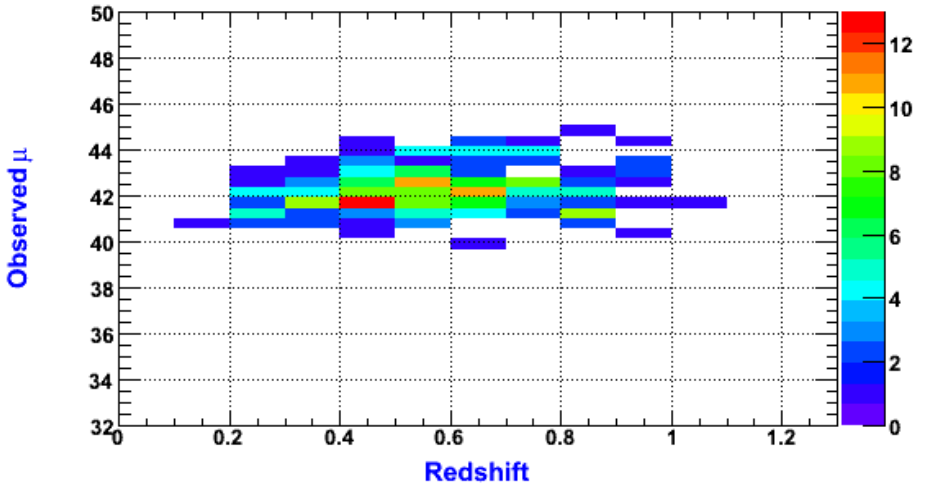
- 5 total epochs above a very small, but non-zero, signal-to-noise threshold
- 1 epoch before and at least 1 10 days after the *B*-band peak
- 1 filter measurement with a signal-to-noise above 10
- 2 additional filter measurements with a signal-to-noise above 5

- 100,664 total SNe generated, 9344 Type Ia
- About 7% core collapse "contamination" with fit prob. cut > 0.1
  - biases cosmology fit by about 6 standard deviations!
- Fit prob. cut >0.5 reduces contamination to about 2%
  - also reduces bias to less than 2 standard deviations
  - trade off is loss of about 20% of the Ia sample

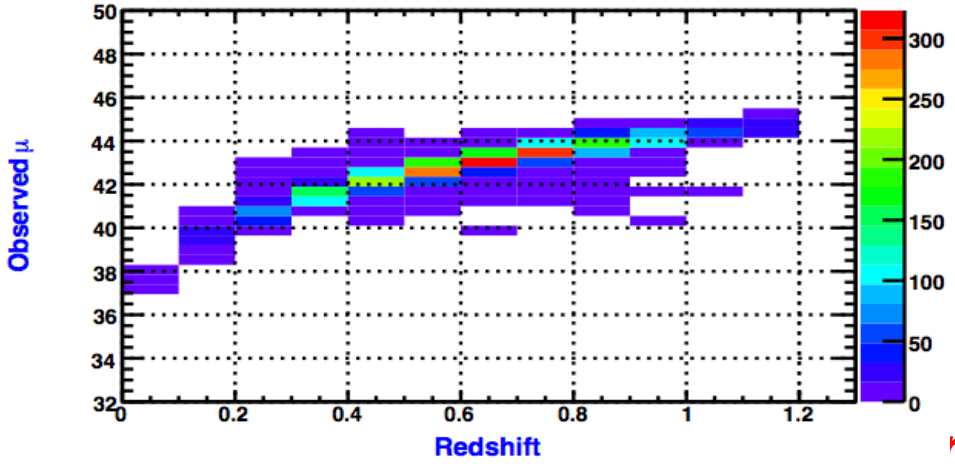
Two Component Fit Alternative to Fit Prob. Cut Increase



Type Ia



Core Collapse



ntire Sample

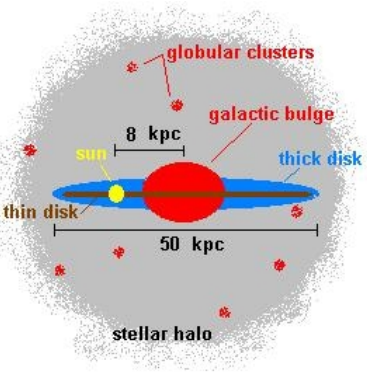
Summary & Conclusions

- Observations show Universe is composed of 95% weird stuff
  - ~21% dark matter
  - ~74% dark energy
- Dark energy: explanation of dimness of distant supernovae
  - fundamental physics mystery: what is it?
  - default theory
    - Einstein's cosmological constant
    - best model is off by factor of 10^{60}
- Supernovae are excellent cosmological tools
- Dark Energy Survey (DES): next step in addressing dark energy
- DES on schedule for first light in 2011

Thanks for listening!

The Blanco & The Milky Way

Image courtesy Mike Fanelli



The Blanco telescope dome at Cerro Tololo, Chile. Single, non-composite image taken using a 2Kx2K scientific CCD temporarily mated to a custom camera. 20 sec exposure, 40mm f/4 lens, starlight only.
Credit: Roger Smith/NOAO/AURA/NSF